The ^{12}C continuum in a microscopic coupled channel calculation*

T. Neff[1,2] *and H. Feldmeier*[1,2,3]
[1]GSI, Darmstadt, Germany; [2]EMMI, Darmstadt, Germany; [3]FIAS, Frankfurt, Germany

For the description of scattering processes and resonances a proper treatment of the continuum is necessary. To achieve such a description in a microscopic many-body approach one has to connect compact configurations that describe the internal part of the wave function with external cluster configurations representing the open channels.

We have developed such an approach within fermionic molecular dynamics (FMD). FMD uses a wave-packet basis that allows to describe the internal parts of the wave function and the external cluster channels on equal footing. The matching to the asymptotic behavior as given by two point-like clusters interacting only via Coulomb is performed in the microscopic R-matrix formalism.

As a first example we discuss the continuum states in ^{12}C. We previously studied ^{12}C in bound state approximation [1]. The focus was on the properties of the Hoyle state, which lies just above the ^{8}Be-^{4}He threshold. Whereas the bound state approximation is expected to work well for a very narrow resonance like the Hoyle state this is no longer true for other resonances like the second 2^+ state. The resonance position and width for this state could only be determined very recently by direct excitation with photons [2]. The existence and the nature of other states in the continuum is still hotly debated.

To address these questions we extend our calculations with a proper treatment of the continuum. Before doing the full FMD calculation a study within the microscopic α-cluster model has been performed. The microscopic cluster model with full antisymmetrization and employing a phenomenological two-body interaction proved to be successful in describing many properties of ^{12}C. In the internal region the Hilbert space is built from three-α configurations on a triangular grid. In the external region ^{8}Be-^{4}He configurations are added. The ^{8}Be eigenstates are obtained in bound state approximation by diagonalizating configurations up to 9 fm distance. Our results will have to be checked for convergence with respect to increasing the number of included ^{8}Be (pseudo-) states. Technically the challenge is related to the restoration of rotational symmetry. First the intrinsic wave functions for ^{8}Be have to be projected on good angular momentum. In a second step the ^{8}Be-^{4}He configurations (with different orientations of the ^{8}Be spin) have to be projected on total angular momentum. For solving the Schrödinger equation with the microscopic R-matrix method, Hamiltonian and norm kernels for the different channels have to be calculated.

In Fig. 1 the calculated phase shifts (from the diagonal matrix elements of the coupled-channel S-matrix) in the 0^+ and 2^+ channels are shown. We included here the ^{8}Be ground state and the first 2^+ state at 3 MeV. In the ^{12}C 0^+ channel the extremely narrow Hoyle state resonance at 300 keV is not resolved when scanning over the energy. Its resonance properties can be calculated by employing Gamow boundary conditions. A second 0^+ resonance at 4 MeV is related to the opening of the ^{8}Be(2^+) channel. As can be seen in the inelasticities (the magnitudes of the diagonal S-matrix elements) there is a strong coupling between the ^{8}Be(0^+) and ^{8}Be(2^+) channels. When adding additional ^{8}Be channels we observe additional resonances in the region above 4 MeV. This might explain the experimental observation of a very broad resonance at 10.3 MeV. In the ^{12}C 2^+ channel a resonance of ^{8}Be(0^+)-^{4}He nature at 1.5 MeV is found. In a next step we will calculate the $B(E2)$ transition strength distribution to compare with the experimental result [2]. Additional resonances again appear after crossing the ^{8}Be(2^+)-^{4}He threshold.

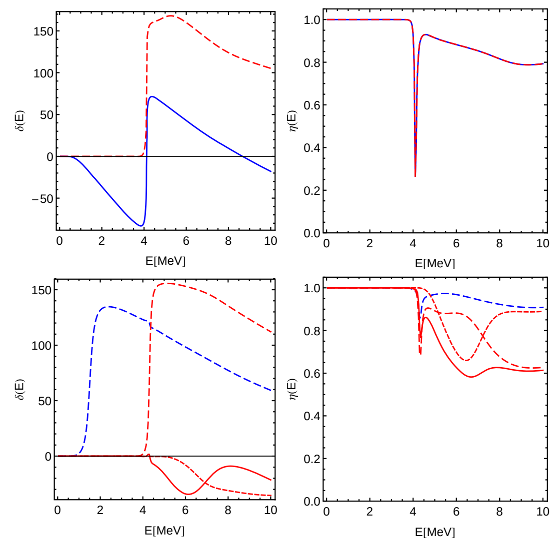

Figure 1: Phase shifts and inelasticity parameters for ^{8}Be-^{4}He scattering in 0^+ (top) and 2^+ channels (bottom). ^{8}Be(0^+) (blue lines) and ^{8}Be(2^+) (red lines) configurations are included.

References

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